CHAPTER 350

Interactions between a Sand Barrier and Flood Terrace at the Abukuma River Mouth

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Abstract

The sand barrier at the Abukuma River mouth flushed by floods in autumn firmly recovered within a half year by stretching its tip to the cross river direction. However, the direction suddenly changed upstream since 1993. This paper analysis the mechanism of the change.

The river has a large terrace formed by the flood in 1986, the maximum in the observed floods over fifty years. Bathymetric data sounded once a year reveal gradual development of a channel on the terrace off the river axis. From wave ray analyses, it is shown the development accompanies change of the refraction characteristics of waves. The channel becomes to function as a half mirror; reflecting waves incoming from one direction and transmitting from the other direction. This is shown to modify direction of dominant waves near the barrier and to turn the stretch direction of the barrier.

The channel evolution is also shown to correlate with the flood outflow.

1 Introduction

Development of sand barriers at river mouths has close influences on the river management such as flood passage and voyage. The barriers also control water salinity inside the river, which relates with water resources and ecological environments. Although the barrier has important roles in the various aspects near the mouth, the mechanism of the development or deformation is not well known.

The difficulties to find the mechanism may mainly come from complexity of the dual external forces of river flows and waves. The complicated topographies inherent to the mouth like flood terraces and sand barriers also tangle the affair, because they cause flow fields and wave fields to considerably deform. Furthermore broadness of the time scale band on the topography change, which would

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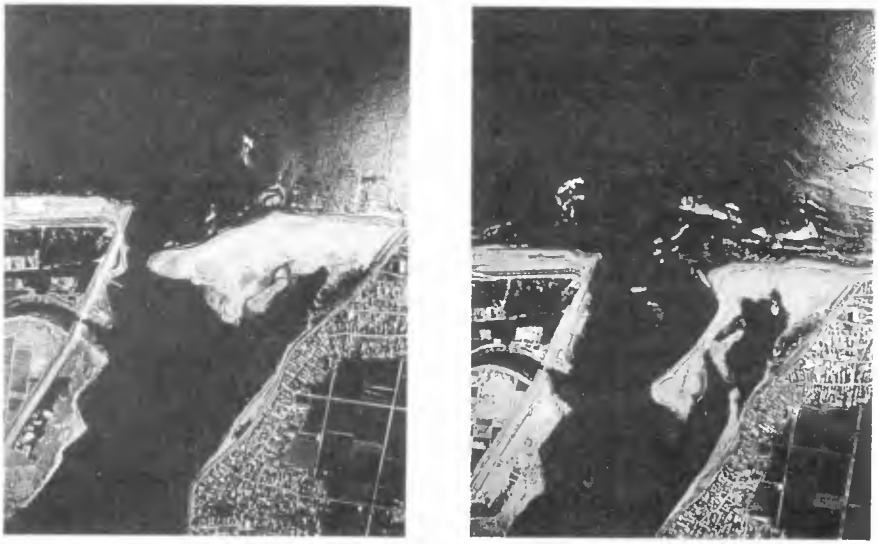
relate with the characteristics of the external forces, requires vast set of observed data in the analyses.

Over twelve years, we have been surveying the sand barrier at the Abukuma River mouth in Japan. The details of the observations on the Abukuma River and the characteristics of the barrier deformation in various time scales have been reported (Mano et al. 1995). This river has a catchment of 5,400 km^2 and a main channel of 239 km. The maximum flood over fifty years of observation by Ministry of Construction occurred on August 1986 with the peak discharge of Q=7,900m$^3/s$ near the mouth. This flood flushed out the sand barrier so far and made a large flood terrace off the mouth.

After the flush by the flood, the barrier started to recover. The tip of the barrier advanced in the cross river direction. Then within a half year, it reached equilibrium such that the minimum opening width at the mouth is maintained by the usual river flows and tides. This elongation is the earliest process in the recovery then thickening barrier followed until the next year's flush caused mainly by typhoons in autumn. After the 1986 event, this cycle of flush and recover had continue for seven years always accompanying transverse elongation of the barrier.

However in 1993, the barrier changed its development from cross-river direction to upstream direction. The typical shapes are shown in Fig.1 (a) and (b).



(a) March, 1991. (b) April 1994.

Fig. 1: Aerial photographs for the typical sand barrier shapes.

After a lapse of more than a half year, both photographs show the fully developed barriers in length. However the shapes are quite different. Figure 1 (a) shows the barrier stretching transversely from the right side bank and very narrow opening width, about 70 m. However Fig.1 (b) exhibits the barrier stretching upstream and the widely opened mouth. Waves are intruding inside the river and two typical arced beaches are formed in the river.

The barrier as Fig.1 (b) has less resistance for the flood passage and provides safer routes for the voyage. Therefore it looks like as if the nature is helping river management since then. The purpose of this paper is to find the mechanism that the sand barrier that had firmly stretched in the cross river direction for seven years changed the direction.

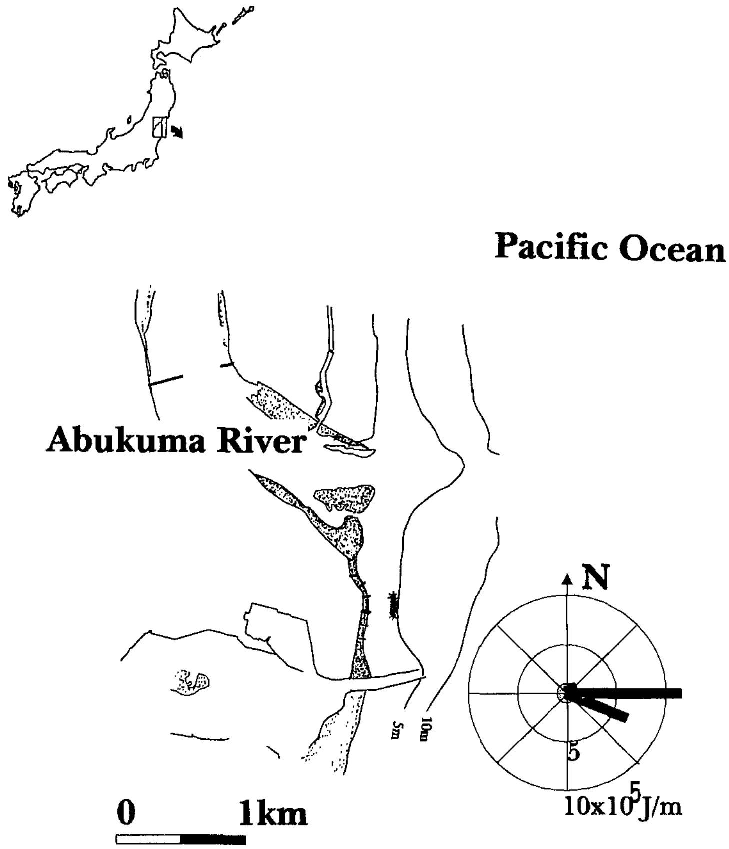


Fig. 2: Topography near the Abukuma River mouth.

2 Topography near the mouth

The Abukuma River flows into the Pacific Ocean, crossing the coast line that has the azimuth, N5°E as shown in Fig.2. No jetties are constructed about the mouth. Waves are observed by the Ministry of Transport off the Sendai Harbor that locates about 25 km north of the mouth. Annual deep water wave energies that are the integration of the energy flux in a year and the averaged values in the period, 1984 to 1992 are also plotted in this figure. The most dominant waves are those of E and have the energy of 11×10^5 J/m that is about 60 % of the total energy. The next dominant waves are those of ESE sharing 35 %. Depending on the directional distribution of the wave energy, the longshore drift around the coast orients north.

The bathymetric charts near the mouth are shown in Fig. 3 (a), (b), (c), and (d) for various stages. Before the 1986 flood, there existed a small terrace in front of the sand barrier and a small channel off the opening, while the barrier was thick. These characteristics correspond to the history of flood activity. Fig. 3 (b), sounded one month after the 1986 flood, showed formation of a large terrace. The top surface of the terrace was very flat with the depth, 4 m. The foot of the terrace reached as deep as 13 m. The mouth was still widely opened.

In 1988, although outline of the terrace was preserved, several deformations were advancing. The shoulder part of the terrace was rounded and the front part of the barrier became shallower. The most remarkable change is the development of a channel on the terrace in the offshore direction from the opening. The opening was usually fixed next to the left side bank by the transverse stretch of the barrier. On the other hand, the terrace was formed along the center line of the river since it was formed by the huge flood that flushed the barrier thoroughly. The position of the channel, therefore, shifted northward from the center of the terrace. In 1993, the channel on the terrace extended offshore.

3 Refraction analysis

To know the influences of the topographic deformations, we have executed wave refraction analysis. Among several numerical methods dealing with the refraction, the wave ray method is especially superior in grasping physical images moreover has the advantage in computational feasibility. Thus we employed the wave ray equation (Mei, 1983) and the refraction coefficient equation (Munk et al., 1952) as follows;

$$\frac{dy}{dx} = \pm\frac{K}{\sqrt{k^2 - K^2}} \tag{1}$$

$$\frac{d^2\beta}{ds^2} + p\frac{d\beta}{ds} + q\beta = 0 \tag{2}$$

$$K = k_o \sin\alpha_o, p = p(c,\alpha), q = q(c,\alpha), K_r = 1/\sqrt{\beta}. \tag{3}$$

Where, x is the local coordinate taken to the steepest gradient of the bottom, y is perpendicular to x, s is the coordinate taken along a wave ray, α is direction

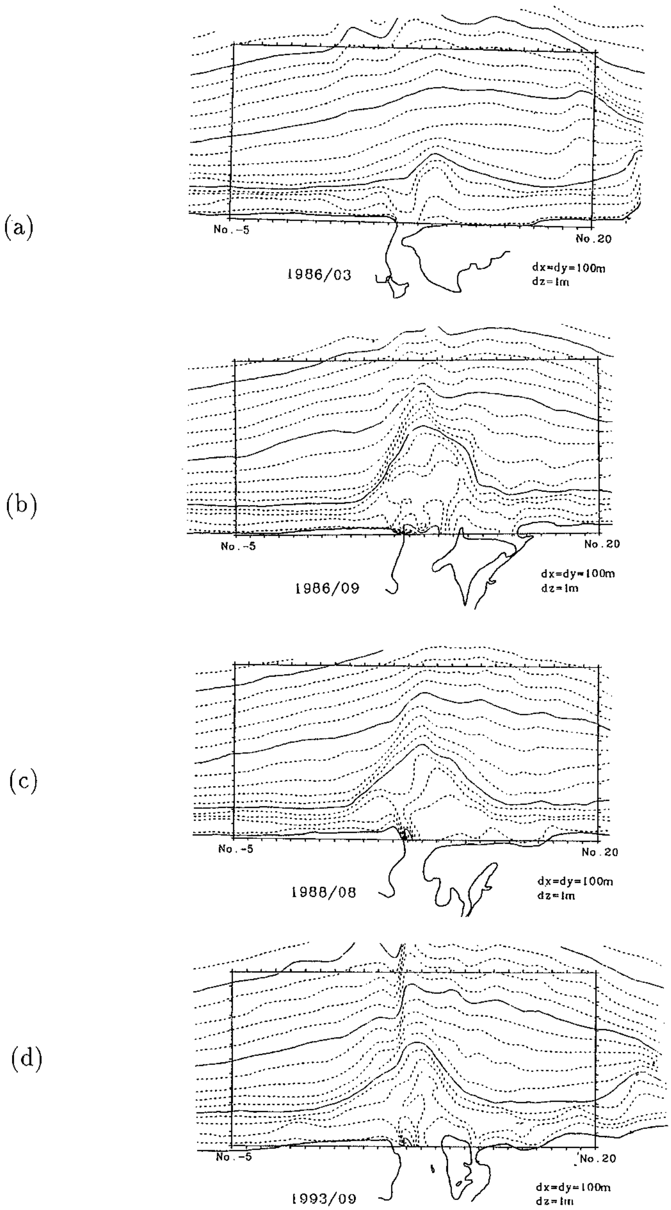


Fig. 3: Bathymetric charts at various stages.(a): March, 1986,(b): September 1986,(c): August 1988,(d): September 1993.

of wave ray, k is the wave number, c is the phase velocity, K_r is the refraction coefficient, and subscript o denotes the boundary value. These equations are solved together with the dispersion relation and boundary conditions by the finite difference method. The employment of the local coordinate x has such an advantage that it is required to solve only once the dispersion relation for each space step marching.

After digitizing the contour lines of the bathymetric charts, we made bathymetric mesh data and expressed the topography by the sets of plane triangle elements. The wave rays started from the offshore boundary were advanced step by step through the integration of the equations with the local coordinate system.

For the topographies mentioned in Figs. 3 and the corresponding annual mean waves, wave rays were computed as shown in Figs. 4 (a), (b), (c), and (d). The incident wave height and period are 0.77 to 0.88 m and 7.4 to 8.4 s respectively. The breaking point for each wave ray was evaluated by using the breaking index (Goda, 1970) and plotted by the filled circle near the shoreline.

In Fig. 4 (a) indicating wave refraction before the 1986 flood, the wave rays approaches uniformly in the longshore direction except very near the river mouth. The small terrace in front of the barrier gathers the wave rays and focuses at the barrier. While for the topography just after the flood, the large terrace gathers more wave rays and focuses about the middle of the terrace. Most of the wave rays passed the focus reach the north coast of the river. Local focuses are again formed. The sand barrier is outside such wave rays and reached rather direct waves that make the barrier stretch in the transverse direction.

In Fig.4 (c), according to the deformation of the terrace, the wave refraction changes. The sand barrier becomes to get two wave groups; direct waves that are almost straight incident and reflected wave at the channel on the terrace. The intensity of the reflection increases with the development of the channel as shown in Fig.4 (d). Along the long channel from the mouth to the contour of 10 m, caustic, that is, the envelop of the wave rays, is formed. Almost all the wave rays reflected at the channel concentrate at the tip of the barrier in such a way that these waves prevent the crosswise stretch or promote the upstream elongation.

Figures 5 (a), (b), (c), (d), and (e) show the effect of the off shore wave direction for the topography of 1993. Here the direction is taken anti-clockwise from the normal to the coastline. For the positive directions, (a) and (b), although the terrace refracts wave rays complicatedly, it transmits the wave rays and makes them concentrate at the tip of the barrier. On the other hand, for the normal to the negative directions, the caustic is firmly formed along the channel moreover makes concentration at the tip of the barrier. Therefor for the waves of positive direction, the terrace is transparent and acts like a convex lens. However for the waves of negative directions it functions as concave reflector. As a whole, the channel functions like a half mirror. Thus the deformed terrace gathers waves of all direction and focuses at the tip. This an-isotropic characteristic of the refraction comes mainly from the position of the channel that is shifted north

(a)

(b)

(c)

(d)

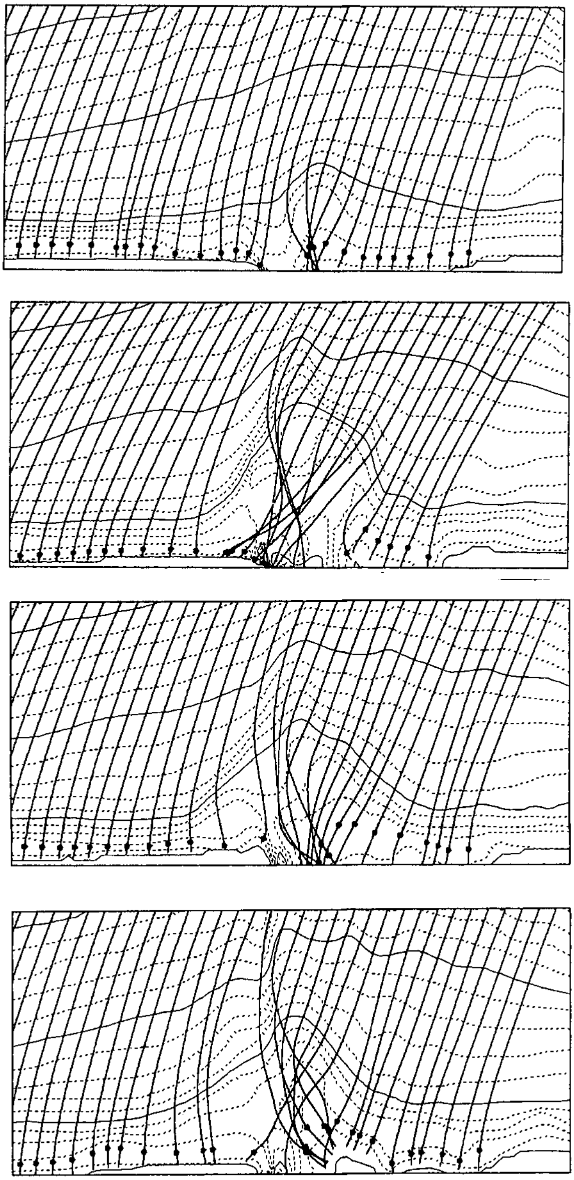


Fig. 4: Wave rays for the topographies at various stages.(a): March, 1986,(b): September 1986,(c): August 1988,(d): September 1993.

(a) $\theta = +45.0^{o}$.

(b) $\theta = +22.5^{o}$.

(c) $\theta = \pm 0.00^{o}$

(d) $\theta = -22.5^{o}$.

(e) $\theta = -45.0^{o}$.

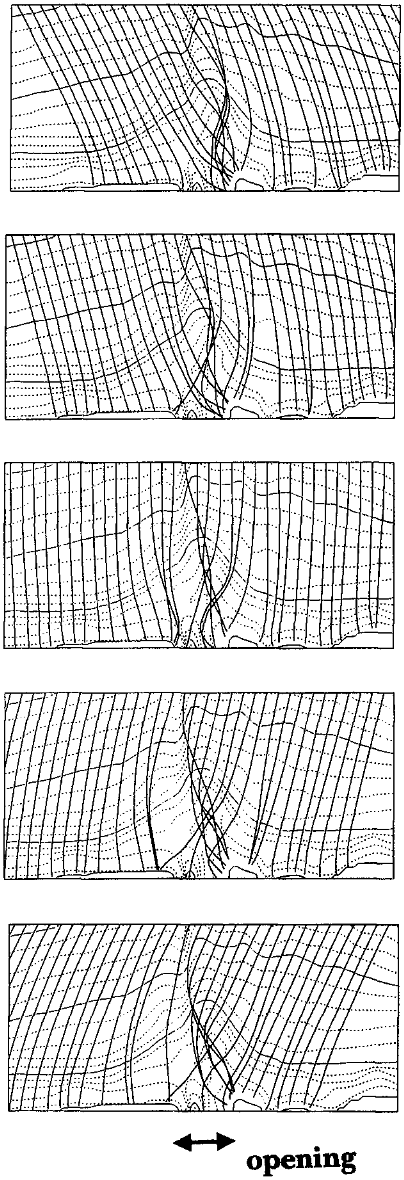
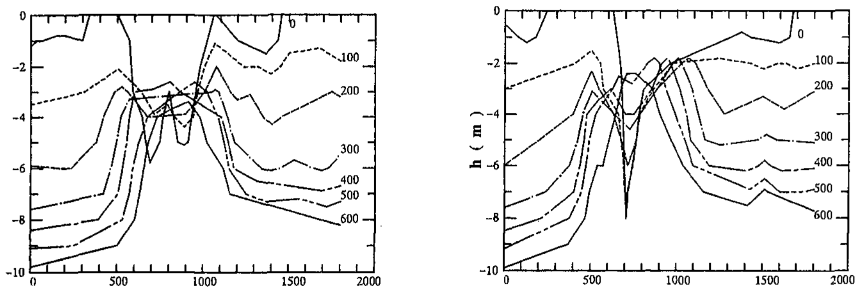


Fig. 5: Effect of wave directions.

from the center of the terrace as stated before.

4 Channel evolution

The next step is to examine how the channel has been developed. The cross sections of the terrace along shore are shown in Figs .6 (a) and (b) for each off shore distance y. The initial shape of the terrace formed by the 1986 flood was almost trapezoidal. Near the mouth there was a broad channel with banks in both sides. Then the banks were disappeared at y = 400m and a very flat and horizontal surface appeared. The depth was about 3 m here.



(a) September, 1986. (b) January 1992.

Fig. 6: Profiles of the terrace.

As time passing, the shoulder parts and the banks near the mouth were eroded to become round and the channel on the terrace was developed. The cross sections on January 1992 (Fig. 6 (b)) indicate a wide and triangular channel on the terrace. By using these profiles, we calculated the channel area that is bordered by the line connecting apexes at both sides. Then the volume of the channel was obtained by integrating the area to the offshore direction till y = 600 m, beyond which the evaluation of the area is not so precise.

Time histories of the volume and the outflow that is the integration of the discharge during the flood are shown in Fig. 7. This figure reveals correlation between the flood activity and the channel evolution. In 1991, we had many floods including large one and the channel volume remarkably increased after the floods. While for the inactive year in the floods, the change of the volume is small. Here the case for the 1986 flood is exceptional. After the largest flood of 1986, the increase of the channel was not so large. This is because the 1986 flood mainly deposited considerable amount of sediment off the mouth. The counted volume was due to the local score very near the mouth and bank formation on the terrace near the mouth.

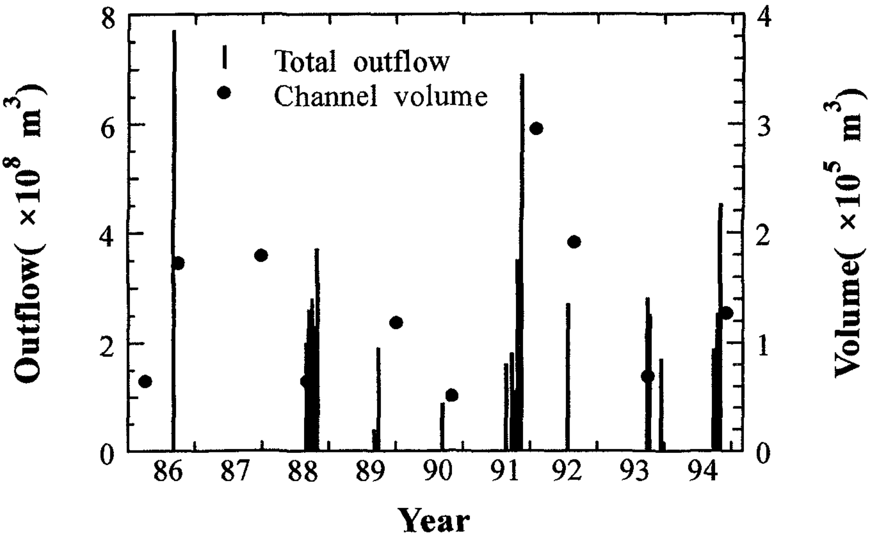


Fig. 7: History of floods and channel evolution.

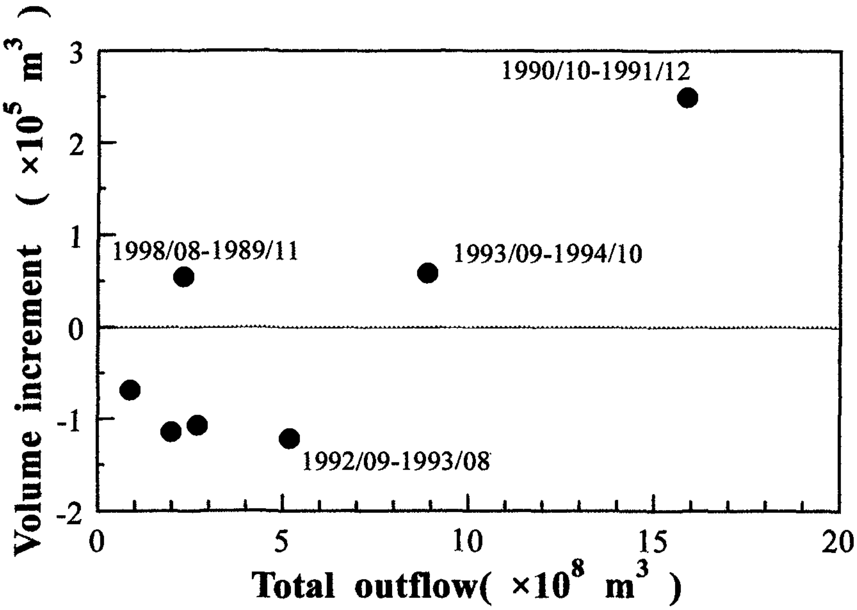


Fig. 8: Correlation between the outflow of the floods and increment of the channel volume.

The correlation between the flood activity and the increase of the volume is examined in Fig. 8. The ordinate indicates the increment of the channel volume obtained from the successive bathymetric charts. The abscissa is the sum of the outflow in the corresponding period. For the large value of the outflow, these two quantities are in linear relationship. While for the small value, the decrement of the channel volume appears, which would correspond to the deposition by waves. Thus the evolution of the channel on the terrace is related with passage of the small to middle scale of floods, except such a huge flood as to make a terrace.

5 Considerations

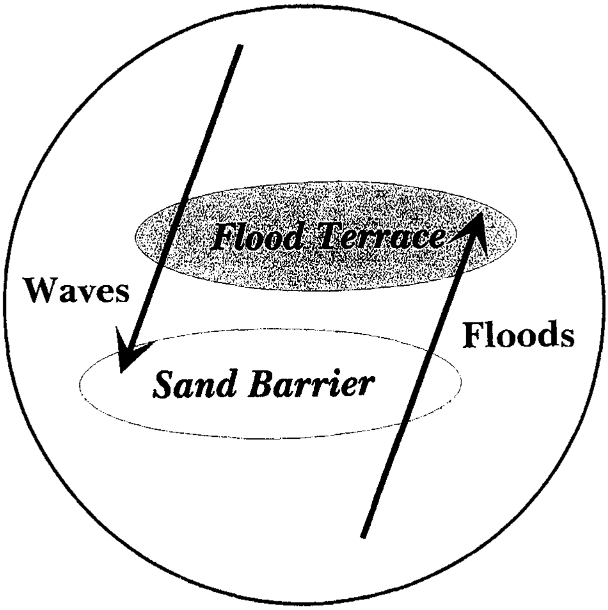


Fig. 9: The river mouth system at the Abukuma River

Starting from the terrace formation by the 1986 flood as an initial stage, here we summarize the flow of the cause and effect in the morphological change in the river mouth system. In the early stage after the terrace formation, the large terrace refracts waves to stretch the sand barrier in the cross river direction. The stretch takes half a year at most. Thus till spring, the opening of the mouth reaches equilibrium maintained by tides and usual river flows with narrow width. Then it is forced to lie adjoining the left bank of the river. Then thickening of the barrier as the following step of the development continues until next flood season. In autumn we have several floods mainly caused by the rainfall due to typhoon. For the small to middle size of floods, they may flush the barrier partly, however the major part of the flow runs out through the old opening. Then it erodes the terrace. The channel on the terrace gradually evolves along the flow axes.

The evolution of the channel also changes the refraction characteristics on the terrace. The reflected waves at the channel are gradually intensified and gathers at the tip of the barrier such a way as to suppress the cross ward stretch. When the reflected waves become dominant to the direct waves, the barrier stops transverse stretch and turns to the upstream direction. The transverse stretch lasted about seven years, while the fixation of the opening to the left bank contributes the channel evolution.

After the turning point, since the opening remained widely open, the reflected waves intrude inside the river and transport the sediment upstream. The waves also make the circular shore lines as shown Fig. 1 (b).

Figure 9 summarizes the interactions between the typical topographies; the sand barrier and flood terrace under the action of the external forces; floods and waves.

6 Conclusions

Based on the bathymetric chart, sand barrier survey, hydro-graphs of floods and wave data over ten years as well as the refraction analysis, we have shown the interactions between the sand barrier and flood terrace under the action of floods and waves. The different time scales on the deformation of these topography also have roles on turning the stretch direction of the barrier.

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